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An Online, Interactive Approach to Teaching Neuroscience to Adolescents

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Most of today's students are skilled in instant messaging, Web browsing, online games, and blogs. These have become part of the social landscape and have changed how we learn and where we learn. The question becomes how to harness the attractiveness and ubiquity of electronic venues toward the goal of teaching neuroscience. At the Rice University Center for Technology in Teaching and Learning, a central focus is the creation of innovative materials that appeal to middle school students. A recent project was undertaken through a Science Education Drug Abuse Partnership Award (R25 DA15063) from the National Institute on Drug Abuse to inform adolescents about the neurobiology of substance abuse and the current research dealing with a class of drugs known as club drugs. Problem-based learning, multimedia pedagogy, and the National Science Content Standards were integrated to produce The Reconstructors™, an episodic series available via the World Wide Web at http://reconstructors.rice.edu. A field test of students from five schools assessed the retention of content after "playing" The Reconstructors™ series titled *Nothing to Rave About*. Gain scores indicated that middle school students' knowledge about club drugs and the basic neuroscience concepts that explain their effects improved significantly.

INTRODUCTION

The rapid acculturation of technology in the United States offers a challenge to science educators. Changes in how we interact (Turkle, 2004) and where we learn (Brown, 2005) are part of the new technology landscape. Yet what happens in schools is often far removed from the wired world that students encounter outside of school (Papert, 1993; Miller *et al.,* 2000; Cuban, 2003). The recent study *The Digital Disconnect: The Widening Gap between Internet-Savvy Students and Their Schools* (Levin and Arafeh, 2002) provides ample data to support this claim. That is not to say that science content should be watered down or trivialized to accommodate the Net Generation's learning preferences or the bells and whistles of multimedia. Rather, our premise is that technology affords new formats of instruction, which, when well grounded in learning theory, can succeed in teaching neuroscience concepts to Net Generation learners in meaningful ways.

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A 2002 report by the U.S. Department of Commerce revealed that, of all demographic groups, teenagers and preteens are the most frequent users of computers and the Internet (U.S. Department of Commerce, 2002). The study found that in 2001, nearly two-thirds (65%) of 10- to-13-yr-olds used the Internet, either at home or at school. The proportion of technology use rises to three-quarters (75%) among 14- to 17-yr-olds. Although Hispanics and African Americans aged 10–17 showed the lowest rates of use (48 and 52%, respectively), these groups also show the fastest rate of increase in use. Schools are increasingly providing technology access to students without home Internet access through after-school programs. In 2002, 73% of secondary schools offered students opportunity for computer time outside of traditional school hours (U.S. Department of Education, 2003). Additionally, the 2001 study found a sizable number of blacks (39.4%) and Hispanics (32%), ages 10–17, take advantage of the Internet at libraries.

Along with the shift toward greater bandwidth and ubiquitous technology access, there has been a simultaneous shift in the learning paradigm. With the advent of constructivist theory, what it means to "know something" has been

transformed from being able to recite facts to being able to learn the facts and apply them, often to solve a specific problem (Brooks and Brooks, 1993). The constructivist approach has many permutations, but might be characterized by the following: Knowledge is constructed by the learner and best retained when it is set in a context, involves active participation, and is scaffolded to build upon prior knowledge. Problem-based learning (PBL; Barrows and Tamblyn, 1980; Lambros, 2004) is one example of a pedagogical approach that uses constructivist theory. It encourages the learner to construct knowledge in the quest to solve a specific problem. It also provides a context through which prior knowledge can be associated with new knowledge. Marrying this PBL approach, which has gained broad acceptance in many professional schools, with multimedia technology provides a type of hybrid instructional plan that can be delivered to a middle school audience through an instructional format described as "Web adventures" (Miller *et al.*, 2001, 2002)

A key feature of the Web adventure format is that it draws from the research of Laurilard *et al.* (2000) and Plowman (1997) regarding the value of narrative or storytelling as aids to the learning process. The narrative approach also reflects the anchored instruction research (Cognition and Technology Group at Vanderbilt, 1993) used to build multimedia environments that have significant learning outcomes. The task of blending best pedagogical practice with the multimedia formats is challenging yet very possible (Moreno and Mayer, 1999, 2000). The use of technology undergirded by cognitive theory is the basis for solid instructional design. Tools such as Macromedia's Flash (San Francisco, CA) offer an efficient and reliable way to incorporate games, virtual labs, and a wide array of interactive techniques that support learning (Miller *et al.*, 2003).

The narrative storyline may serve as a form of PBL when appropriately framed. In The Reconstructors™ series, the Web adventures pose a problem, invite players to solve a problem, and introduce a cast of characters that not only serve as "intelligent agents," but also serve as the literary device to move the storyline forward. The problems in The Reconstructors™ Web adventures are crafted to capture students' interest and motivate them to pursue further inquiry. The storyline is presented episodically. Each episode is approximately 20–30 min in length, with a "cliff-hanger" at the end of Episodes One and Two, intended to serve as motivation to continue.

The Science Content

An overarching purpose of The Reconstructors™ Web adventure series was to introduce substance abuse from a neuroscience perspective (as opposed to a life skills approach). Teaching why a person should say "no" to drugs was the central focus. This approach provides students with the scientific basis for concerns about substance abuse and arms students with a critical filter through which to make not only their own personal health choices, but public policy in the future.

Conversations with science teachers and sciences supervisors led to the conclusion that the pressure to cover a wide variety of science content makes it unlikely that they would be able to devote much time to neuroscience or drugs of abuse. However, the Web adventure format overcame several concerns about time and correlation with other mandated curriculum content. The time it takes to use the Web adventure format is relatively short, thus allowing the adventure to serve as a "plug-in" to the regular curriculum or to be played at home (in instances where the students had access). Several teachers reported using the Web adventures in conjunction with units on the nervous system, thus incorporating a new element rather than totally revising their present curriculum.

Another key element in promoting the Web adventures' use is their alignment with the following National Science Content Standards (National Research Council [NRC], 1996) that are specifically targeted for grades 5–8:

- Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for investigations, or develop new technologies to improve the collection of data.
- Specialized cells perform specialized functions in multicellular organisms.
- Technological solutions have intended benefits and unintended consequences.
- Some drugs change how the body functions and can lead to addiction.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

In response to the question, "What do we want middle school students to know about club drugs?" teachers and scientists on the Advisory Panel provided guidance in defining specific learning objectives. These objectives were then chunked by episode to make a reasonable and scaffolded sequence.

EPISODE ONE

1. Distinguish the physiological effects of a stimulant and a hallucinogen.
2. Recognize that certain drugs can be both stimulants and hallucinogens.
3. Identify the parts and the functions of the brain affected by stimulants.
4. Interpret data and draw conclusions from virtual experiments on the effects of certain drugs on the body.

EPISODE TWO

1. Analyze the content of an unknown substance using mass spectrometry.
2. Examine the negative social and health consequences of club drugs.
3. Learn the basic characteristics of different types of club drugs.
4. Select behaviors that would avoid the risks of club drugs.

EPISODE THREE

1. Analyze the acute and long-term effects associated with taking ecstasy based on current research.

2. Recognize the importance of serotonin in regulating mood, memory, and other body functions.
3. Learn how ecstasy alters the normal communication between neurons.
4. Identify problems with and approaches to studying ecstasy use in humans.

Using this content, The Reconstructors™ scenario shown in Box 1 provided the context and problem to be solved. Placed within the framework of the futuristic society of Neuropolis, The Reconstructors™ Web site presents an engaging problem to solve using scientific inquiry methods and research.

Box 1. The problem developed for the player to solve sets up the scientific investigation through a storyline

> It is the year 2253, eleven years after the Great Plague that ran through the Earth's population, killing millions and causing the collapse of civilization.
>
> You are a member of The Reconstructors, an elite team charged with safeguarding public health in this dark time. The Reconstructors have a new medicinal mystery on their hands.
>
> There has been a dramatic increase in the number of young persons admitted to the Emergency Room in Neuropolis.

During the adventure, students receive help via the on-screen characters who assist in conducting both field and laboratory exercises as captured in Figures 1–3.

The program raises questions at critical junctures to ensure that players understand the process or the content just covered. If incorrect answers are selected, the program provides tutorial feedback and an opportunity to answer again after review. The club drugs narrative, the *Nothing to Rave About* series, unfolds along these lines.

Episode One

In the role of a Reconstructor, the student is challenged with uncovering why there has been a dramatic increase in the number of teens admitted to the hospital emergency room in Neuropolis. A teen patient is interviewed to learn his symptoms. The preliminary facts suggest that a drug with both stimulant and hallucinogenic properties is the cause of the problem. Through an examination of Reconstructor files, the student learns about brain areas affected by stimulants and their behavioral effects.

Episode Two

The student follows two lines of inquiry in an effort to learn more about the mystery drug. In the lab, he/she analyzes the substance using mass spectrometry and determines that it is the drug 3,4-methylenedioxymethamphetamine, known on the street as ecstasy. At police headquarters, the student reviews recent cases involving the club drugs such as ecstasy, alcohol, methamphetamine, and γ-hydroxybutyrate. In a segment called "Street-Wise," the player has an opportunity to role play how he/she would handle different social situations involving these substances.

Episode Three

After news of police closing the dance club reaches the media, a music talk show host is inundated with inquiries about the use of ecstasy. The Reconstructors team is asked to appear on the talk show to explain. The player must learn more about the effect of ecstasy. Specifically, the player 1) plays a game titled Synaptic Salvo that simulates ecstasy's actions on serotonin neurotransmission; 2) learns that animal studies indicate long-term ecstasy use may damage

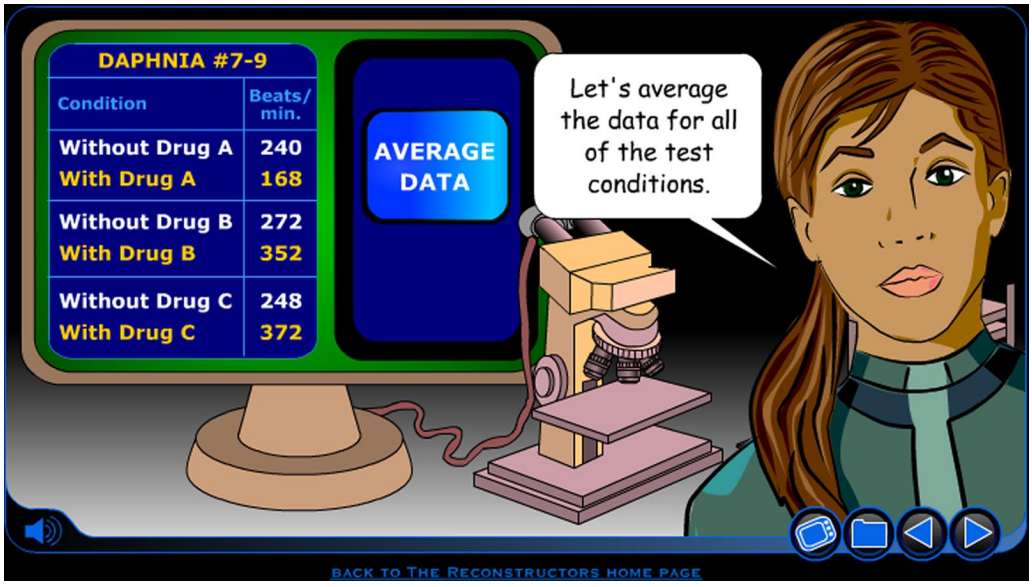

Figure 1. Example of virtual lab.

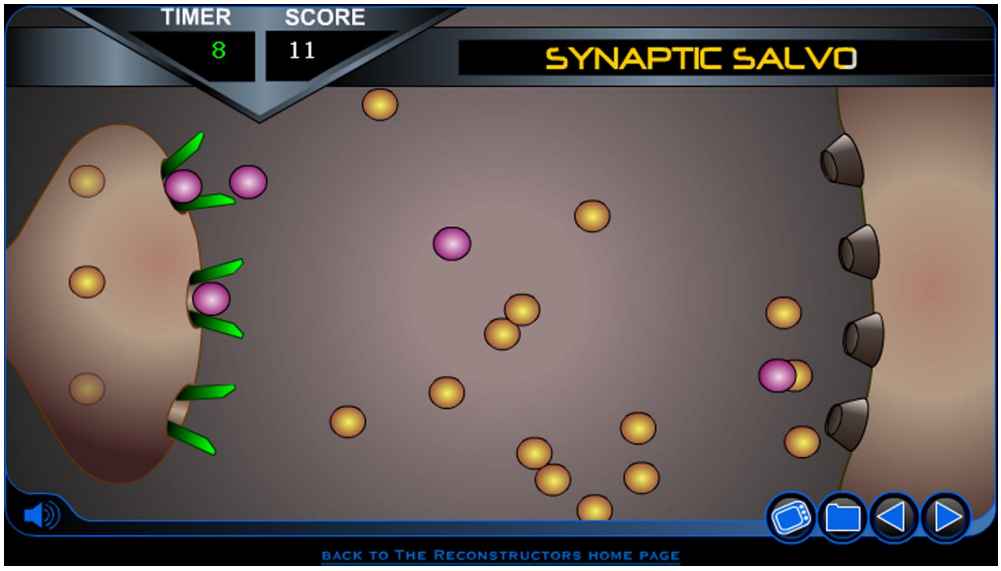

Figure 2. Screen capture from the Synaptic Salvo game.

serotonin neurons; 3) examines functional magnetic resonance images showing differences in brain activity between ecstasy users and nonusers; and 4) reviews memory tests and mood studies that reveal how repeated use of ecstasy can lead to deficits in these capacities.

METHODS

Procedure

To test the learning impact of the Web site independent of classroom instruction, teachers were asked not to preteach the content. Informed consent from students and their parents was obtained through forms (in both English and Spanish) sent home with all potential participants. Teachers were instructed to allow 3 d between each phase: pretest, playing the Web adventures, and post-test.

The actual Web site use occurred in the school's computer lab with approximately 25 students using the adventure independently on separate workstations. Only students who returned a signed parental consent form took part in the evaluation, but this number was typically more than 95% of the students in each class. The evaluation instrument consisted of a 35-item pretest and a 35-item post-test, with the same questions randomized in a different order.

Participants

At national or regional science meetings, volunteer teachers were recruited who could meet the following criteria: 1) principals at each school endorsed participation in the study and 2) the necessary

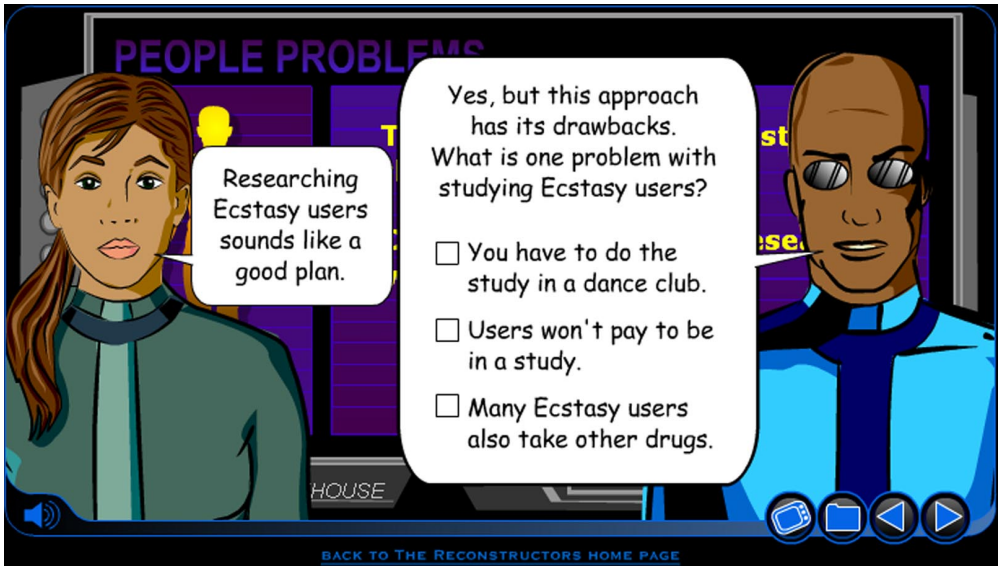

Figure 3. Example of check for understanding.

computer access was guaranteed. The final sample of five schools was selected to provide for regional variation and included two urban schools, two suburban schools, and one rural school. School 1 is in an urban community in Washington state and is predominantly white, with over one-third of the students qualifying for free and reduced lunch. School 2, in a Texas suburban area, is ethnically diverse, with a high percentage of minority enrollment. School 3 is a Nevada rural school, with a lower minority enrollment than the other schools in the study. Data were not available for free or reduced lunch status because this school did not have a lunch program because of its small size. School 4 is a Texas urban math/science/arts magnet school, with a population distributed almost evenly between black and Hispanic students. School 5 is a Colorado suburban school, with a predominantly white enrollment (Table 1).

A total of 289 students (159 girls/130 boys) completed all three instruments. At the time of the evaluation 209 students were in seventh-grade science classes and 80 students were in eighth-grade science classes. The mean age of the sample was 13.0 (SD = 0.73). The majority of students were white (n = 159, 55% of the total), followed by Hispanic (n = 42, 14.5%), black (n = 27, 9.3%), and Asian (n = 20, 7%). A few students identified themselves as American Indian (n = 10, 3.5%), or Native Hawaiian/Pacific Islanders (n = 9, 3%). Fifteen students represented themselves as "mixed" (5%), and seven students (2%) did not identify their race.

Instruments

Paper and pencil pretests and post-tests normally took students between 15 and 30 min to complete. The pretest included 35 multiple choice science content questions (10 from Episode One, 12 from Episode Two, 13 from Episode Three). All 35 items were randomized so that questions from the same mission were not grouped together. The post-test included the same 35 multiple-choice content questions, but they were randomized in an order different from the pretest. Examples of the questions are presented in Box 2.

Box 2. Sample questions from tests

Neurons communicate across a tiny space called:
a. Action potential
b. Neurotransmitter
c. Synapse
d. Transporter

A chemical that sends signals from one neuron to another is called:
a. Acetaminophen
b. Enzyme
c. Mescaline
d. Neurotransmitter

Animal studies show that Ecstasy can damage neurons and cause them to produce:
a. Less serotonin
b. Less ketamine
c. Less amphetamine
d. Less mescaline

One area of the brain affected by stimulants which is important for learning and memory is the:
a. Amygdala
b. Brain stem
c. Hippocampus
d. Hypothalamus

Ecstasy interferes with serotonin reuptake by:
a. Blocking the transporters
b. Destroying neurotransmitters
c. Releasing antidepressants
d. Retaining methamphetamines

Cocaine, nicotine, and ephedra are examples of:
a. Amphetamines
b. Hallucinogens
c. Methamphetamines
d. Stimulants

RESULTS

The first level of analysis was a comparison of the total sample's pretest-to-post-test gains on each episode. Scores were corrected for guessing by awarding one point for each item answered correctly, subtracting 0.25 points for each item answered incorrectly, and giving no credit or penalty to questions left blank. The percent correct scores (corrected for guessing) by episode are presented in Table 2. Paired *t* tests showed that there was a significant gain in all three episodes: Episode One, t (df 288) = 5.16, $p < 0.001$; Episode Two, t (df 288) = 12.03, $p < 0.001$; and Episode Three, t (df 288) = 19.00, $p < 0.001$. An analysis by gender revealed no significant effects.

A further analysis was conducted to determine differences by school in an effort to detect the Web site's suitability for a variety of student populations. Findings from the Episode One analyses showed that there was variation among the five schools with regard to pre-existing science content knowledge (Table 2). Pre-existing knowledge ranged from 51% in School 5 and 17% in School 2, with the other three schools falling somewhere in between. An item analysis of questions in Episode One indicated that before using The Reconstructors™, students at all schools were most familiar with the "effects of stimulants." Two items on the pretest covered this topic, and 60% of students answered correctly on both of the items. The percent correct moved to 78 and 75% on the post-test. One of the least-known topics was the area of the brain responsible for learning and memory that is

Table 1. School profiles by ethnicity and socioeconomic status

	African American (%)	Hispanic (%)	Other (%)[a]	Free/reduced lunch (%)
School 1: WA	8	10	82	37
School 2: TX	12	27	61	32
School 3: NV	0	7	93	Too small to offer free lunch
School 4: TX	46	41	13	61
School 5: CO	1	8	91	22

[a] This percentage includes Caucasians, Asians, and Native Americans in the school as a whole.

Table 2. Mean percent correct for each episode

	Overall	School 1	School 2	School 3	School 4	School 5
No. of students	289	68	53	68	44	56
Episode One						
Pretest	26 (24)	17 (19)	13 (21)	27 (21)	20 (18)	51 (23)
Post-test	33 (27)	18 (21)	26 (26)	34 (25)	36 (21)	56 (26)
t	5.16[a]	0.26	3.73[a]	2.13	3.88[a]	2.15[b]
Episode Two						
Pretest	34 (24)	24 (21)	22 (24)	42 (24)	35 (18)	46 (22)
Post-test	51 (21)	44 (17)	44 (22)	48 (23)	61 (16)	61 (20)
t	12.03[a]	6.67[a]	6.64[a]	2.09[b]	8.31[a]	5.49[a]
Episode Three						
Pretest	33 (22)	23 (18)	22 (21)	32 (23)	43 (19)	47 (19)
Post-test	61 (26)	48 (27)	57 (24)	57 (28)	85 (13)	66 (21)
t	19.00[a]	7.68[a]	11.02[a]	7.32[a]	13.65[a]	7.38[a]

SDs appear in parentheses.
[a] $p < 0.001$; [b] $p < 0.05$.

affected by stimulants (hippocampus). The percent correct moved from 21 to 47% correct on the post-test.

Findings from the Episode Two analyses also indicated a significant overall gain of 17%. Overall scores moved from 34 to 51% correct; moreover, the same pattern of a variation in pre-existing neuroscience content knowledge and the final outcome scores among schools continued, with Schools 5 and 2 setting the range (Table 2). The pretest knowledge ranged from an average percent correct of 46% in School 5 to the average pretest score of 22% correct in School 2. These scores all increased significantly on the post-test to a total percent correct at the respective schools of 44 and 61%. In this episode, the student is introduced to using mass spectrometry as a means of analyzing an unknown drug and the social and health consequences of club drugs. An item analysis revealed that students were most familiar with the question asking about the effects of ecstasy (56%), the effects of date rape drugs (60%), and the effects of alcohol (80%). These three questions increased to 72, 72, and 86%, respectively, on the post-test. The greatest gains in item scores were realized on the questions dealing with the purposes of a mass spectrometer (a 31% increase in percent correct) and on the question about which drug has the properties of both a stimulant and a hallucinogen (ecstasy). This question had a 39% increase.

In the final, and perhaps most complex episode, which covers the acute and long-term effects associated with taking ecstasy, the role of serotonin in regulating mood, memory, and other body functions, and the actual blocking of serotonin receptors by ecstasy, there were significant gains. The overall percent correct changed from 33 to 61%. The item analysis revealed the item dealing with a fairly sophisticated concept (i.e., ecstasy interferes with serotonin reuptake by blocking the transporters) received the greatest gains from 26 to 75% correct for a gain of 49%.

DISCUSSION

The initial proposition that neuroscience instruction can benefit from the exploration of new learning environments finds support in these data. More specifically, students retain neuroscience content when it is placed in an engaging context and reinforced through multimedia games, virtual labs, and interactive quizzes. There is some concern that the gain scores do not reflect 100% mastery of the information. In fact, one might argue that the 61% achieved in Episode Three is relatively low, given the customary ideal of every student achieving at least 70% for "passing." However, given the extremely small amount of time spent and the unfamiliarity of many of the concepts, it does not appear as surprising. Viewed from the perspective of time-on-task, the investment of approximately 30 min in each Web adventure has extremely efficacious results. Student learning among a wide range of school populations was positively impacted. It would be fair to assume that by adding teacher-guided inquiry, hands-on activities, and follow-up discussion, the learning gains would be even greater than in this study. Feedback from teachers who use The Reconstructors™ indicates that they often use the Web adventure as the "engagement" phase of Bybee's 5Es model of instruction—Engage, Explore, Explain, Elaborate, and Evaluate (Bybee, 1997). The purpose of "engagement" is to grab the students' attention, to put students into a receptive frame of mind, and to create an organizing framework for the ideas or information that follows. The Reconstructors™ is not comprehensive with regard to neuroscience content, but it does move the student up the scaffold of neuroscience knowledge, perhaps more so than an equivalent time-on-task of a different instructional approach. A next logical research question would compare the efficacy of The Reconstructors™ with alternative forms of instruction.

Despite these limitations and the need for further study, there is an overall sense that the middle-school-age audience can approach some relatively complex neuroscience concepts successfully through this format. For example, the concept of ecstasy blocking serotonin reuptake is conveyed through a game entitled Synaptic Salvo. In this game, the player has to move balls through a specific entry point. Once this game is played, an analogy to the neurotransmission that occurs as ecstasy blocks the serotonin transporters is

given. The game is replayed with the appropriate labeling of the process. It is doubtful whether such a high percentage of students (76%) would have recalled this effect of ecstasy 3 d after classroom instruction without an engaging instructional delivery method.

Yet another advantage of the Web adventure format is the ability to craft an interactive segment that best suits the learning objective and to present the same concept through more than one technique. For example, interactive segments can employ drag-and-drop features, multiple-choice items, virtual labs, or adaptations of well-known computer games. Instructional designers can exercise creativity as well as follow sound learning principles when conveying neuroscience content.

In summary, The Reconstructors™ uses the context of substance abuse to engage adolescents in problem solving and to introduce fundamental knowledge about related aspects of neuroscience. The power of Web adventures to engage students sets a robust context for the construction of neuroscience knowledge. Whether the learning gains reported here would be obtained for other methods and different audiences remains to be tested; however, the opportunity to "reconstruct" neuroscience is limited only by the creativity and instructional design strategies of the science community.

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